LECTURE

DELIVERED BEFORE THE SMITHSONIAN INSTITUTION.

ON METEOROLOGY.

BY ROBERT RUSSELL, ESQ.,* OF SCOTLAND.

First Lecture.

To study the peculiarities of the atmospheric changes in North America, and the effects of the climate on agriculture, are the principal objects for which I have visited this part of the world. I am much gratified to find so large a number of meteorological observers scattered over all parts of this vast continent, contributing so materially to the advancement of science.

Since I have had an opportunity of studying the meteorology of the United States, I have been much impressed with the limited area of the field for investigations within the British islands. It now appears as a mere handbreadth, in comparison to the wide territory over which you are prosecuting your inquiries into the causes of atmospheric disturbances.

Your government has done considerable for the support of meteorology. It has accumulated at the National Observatory, under the direction of Lieutenant Maury, an invaluable collection of facts relative to the sea. It has established observations at each of its military posts, and has secured the services of Professor Espy, who has done more for theoretical meteorology, in my opinion, than any other living man.

But I must confess that I would have turned my face to the Old World somewhat unsatisfied, if I had not had, through the politeness of the Secretary, an opportunity to examine the meteorological records collected within the walls of this Institution, and, through them, to become acquainted with the peculiarities of your climate; and to trace out the nature and extent of some of the atmospheric disturbances which had attracted my attention during my tour.

In this short course of lectures I shall not enter upon those questions which relate to general meteorology, but shall confine myself principally to the analogies which seem to subsist between the action of atmospheric agents in Europe and in North America, and point out a few facts which demand more extended observations for their solution.

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*Note.—The author of these lectures came to this country with letters of introduction from Sir David Brewster, Professor Airy, and other distinguished cultivators of science in Great Britain. The Smithsonian meteorological records were opened for his investigation, and other facilities extended him for the prosecution of his studies. Without intending to endorse the peculiar views which he may have advanced, we may say that his lectures contain facts and suggestions fully worthy of attention. J. H.

To comprehend the nature of the changes which the atmosphere undergoes, the elementary principles of meteorological science must be understood; but I do not intend to enter more minutely into these than will enable those who have not devoted much attention to the subject to comprehend the more important truths.

The nature of the atmosphere was long involved in obscurity. Its properties could not be ascertained till chemistry and other branches of natural science were considerably advanced. Air has so little color that it is almost invisible, and offers so little resistance to motion, that it was considered by the school of Aristotle imponderable. This opinion was entertained for many centuries afterwards, until the invention of the barometer, by Toricelli, in 1640, and the discovery of the fact pointed out by Pascal, that the barometer stands lower on the top of a mountain than at its base, left no doubt remaining that air was possessed of weight, and, consequently, that the atmosphere exerted a great pressure.

If a glass tube, three feet in length, be filled with mercury, and its open end inverted in a basin of the same liquid, the mercury in the tube will stand, at the level of the sea, nearly 30 inches higher than the surface of that in the basin. This column of mercury, which, if its section is a square inch, weighs nearly 15 pounds, is balanced by a column of air of the same section and extending to the top of the atmosphere. The pressure of the atmosphere is, therefore, equal to that of an ocean of mercury of 30 inches deep, or to a pressure on each square inch of surface of about 15 pounds. Moreover, mercury is 13½ times heavier than water, and 10,500 times heavier than dry air at the surface of the earth; hence the pressure of the atmosphere is equal to that of an ocean of water of about 33 feet deep, or an ocean of air, of equal density throughout, of 27,000 feet high.

That the atmosphere should press on the surface of the earth, and on all parts of our bodies, with a weight of 15 pounds to the square inch, is, at first sight, a very perplexing fact; but it is fully illustrated by the familiar and analogous pressure of water. The diver who descends below the surface of the sea is pressed on all sides by the superincumbent weight of water, and, instead of being incommoded by this, is rendered more buoyant. The particles of the air are of extreme tenuity and of almost perfect mobility, and therefore offer no resistance to bodies moving among them. On these accounts the weight of the air, and the great pressure of the atmosphere, remained so long concealed.

For a long time after the discovery of the pressure of the atmosphere, the world remained in ignorance of its chemical and mechanical constitution. The analysis of air was, however, one of the first triumphs of modern chemistry. Rutherford discovered hydrogen, one of its components, in 1772; and, two years after, Priestly and Shiel, independently of each other, discovered the other principal ingredient, namely, oxygen.

Dry air is composed of 77 parts nitrogen, 23 oxygen, by weight; 79 parts nitrogen, 21 oxygen, by volume; carbonic acid, 1.1000 by weight; ammonia, only a trace. The atmosphere also contains a certain amount of moisture. This is the only component which is liable to much change in its quantity. It varies from two per cent. to an inappreciable portion.

Again, the chemical composition of air had been established several years before its mechanical character was fully made out. The sages of Egypt and of Greece disputed about the constitution of matter; but their speculations, however ingenious, led to no definite results. At the end of the last century many valuable facts had been accumulated on this point; but no great law had been proposed to link these facts together before JOHN DALTON applied the atomic theory of the constitution of matter to explain the mechanical phenomena of the atmosphere.

Dalton did much for chemical science, and is justly regarded as the father of meteorology. He was gifted with gigantic powers of mind, and, in other respects, possessed a noble character.

Modern science regards matter as made up of atoms endowed with attracting and repelling force. In the case of a solid or liquid, these two forces are in equilibrium—the atoms are held at a distance from each other, and do not fill all the space enclosed within their boundaries. If a solid or liquid is subjected to pressure, the atoms are made to approach each other, and the repulsion is increased; so that, when the pressure is removed, the atoms fly back to their original position. If, on the contrary, we attempt to draw a solid apart, the attraction comes into operation, and offers a resistance which is called cohesion. In the case of aeriform substances, the repulsion entirely preponderates. Dalton gave to this theory a definite form, and applied it to the phenomena of the atmosphere.

All our conceptions of the constitution of substances, in regard to their solid, liquid, or aeriform states, are more or less intimately associated with the atomic constitution of matter in its relations to heat. Thus, the action of heat converts a solid into a liquid, by giving mobility to its atoms. The action of heat converts a liquid into an elastic vapor, or gas, by imparting a repulsive force to its atoms. Indeed, in regard to gases, the repulsive force and heat are often looked upon as identical, and we shall consider them to be so. The elastic properties of gas, steam, or vapor, are, then, owing to the mutual repulsion of the atoms, in consequence of the action of heat. This view, arising naturally out of the atomic constitution of matter, gives an explanation of the mechanism of gases no less simple than consistent.

To illustrate this principle one fact will suffice. If water is converted into steam under the ordinary pressure of the atmosphere, a cubic inch is transformed into about a cubic foot of vapor. The atoms of water are, therefore, twelve times further apart in the case of steam than they are in that of the liquid. The action of heat has had the effect of putting every atom in a state of repulsion with regard to its fellows—every one tends to fly from the other with as much force as if each was under the influence of a powerful spring. The intensity of the repulsion of the atoms constitutes the force of the steam. The elastic properties of the gases of the atmosphere are also owing to the mutual repulsion of their atoms, though the repulsion is much more permanent in this case than in that of steam. No cold or pressure has yet been found sufficient to reduce nitrogen or oxygen to a liquid form.

The bulk of gas is increased by heat, which must not be looked upon as increasing the size of the atoms, but only as increasing the repulsive force between them. The repulsive or expansive force is measured by the weight which it can support. In the atmosphere, the expansive force of a portion of air, or its elasticity, is exactly balanced by the gravity of all the air above it. The weight of the atoms, from the top to the bottom of the atmosphere, amounts, as we have said before, to about fifteen pounds on each square inch; the elastic or repulsive force which keeps the atoms apart is exactly equal to this amount. Gravity and elasticity are so equally poised, and the atoms move so freely amongst each other, that the air is in a state of the most delicate balance that can be imagined.

The expansive property of gases is a remarkable phenomenon in physics. We have no means of ascertaining its limits, but we know if the whole air was exhausted from this room, a single cubic inch of either oxygen or nitrogen would, if admitted into so large a vacuum, instantly occupy every part of it, and still press, though with diminished force, against the walls for further expansion. The repulsive force which exists among the atoms, though greatly weakened, would not be exhausted.

The law which regulates the density and elasticity of gases was discovered about half a century after Toricelli invented the barometer. Mariotte found, by experiment, "That the density and elasticity of atmospheric air are directly, but the space it occupies inversely, as the force of compression." That is to say, if you exhausted the air from the receiver of an air-pump until the barometer stood at fifteen inches, the pressure or elasticity of the air would only be half of what it was before the experiment. It would take two cubic inches of air in this state of rarity to weigh as much as one did when the barometer was at thirty inches; or, in other words, one half of the atoms being removed, the remaining half are further apart, since they still occupy the same space. The number of atoms being reduced one half, if the temperature is the same, their repulsive force is also reduced in the same ratio, and, therefore, the repulsion of the particles of any gas increases as the cube root of the distance between them diminishes. The repulsion between the atom at the very top of the atmosphere and those below it is so much weakened by separation that it is precisely equal to the weight.

From the simple fact that the repulsion of the atoms of gases varies as the number of atoms contained in a given space, it follows that the elasticity and density of a gas are as the pressure directly, that the volume is as the pressure inversely, and that, consequently, the one can be deduced from the other by the simple rule of proportion. This law holds true in regard to the most minute additions of weight, and we have the full assurance of reason, founded on experiment, other things being equal, that the distance which separates every atom of air from the top to the bottom of the atmosphere decreases as we descend; in short, each atom is nearer the atom immediately below it than the one above. The various strata of the atmosphere thus in some measure resembles fleeces of wool or loose balls of cotton piled upon each other. The wool or cotton is more compressed, and therefore more dense, in proportion to the weight it bears; it is most so next the bottom, and least so at the top. The air, in the same way, is more rare as we ascend to greater heights, the atoms being farther apart, and their repulsive force diminished. In consequence of the great capabilities of gases for expanding with diminished pressure, the atmosphere, instead of being only about five miles in height, as it would be if of equal density with the lowest stratum, (?) is really upwards of fifty miles high.

The atmosphere is not only in a most delicate state of balance in respect to elasticity and pressure, but it is no less so in respect to the amount of heat contained in its different strata. The expansive force of gases, or the repulsion which exists among their atoms, seems, as we have already stated, to be identical with heat. When air, at the temperature of freezing water, is condensed in the hollow globe of an air-gun, an immense amount of heat becomes sensible. Tinder, it is well known, can be lighted with a single stroke of a condensing syringe. In the rarefied gas a large amount of heat is stored away and inappreciable by our instruments or senses, which is again given out by compression.

The intimate connexion subsisting between heat and the expansion of gases is most beautifully seen in the atmosphere. As already stated, the atoms of air as we ascend are at greater distances from each other. If the distance between any two atoms is diminished, they give out heat or render it sensible; whereas, if we increase the distance between them, they store it away. The upper strata are sensibly colder than the lower, not because the atoms have less heat, but because the heat is diffused through a larger space when the atoms are farther apart. One pound of air at the level of the sea, within the tropics, may be said to contain no more heat than the same weight at the top of the highest mountain perpetually covered with snow. It is for this reason that the same wind which is warm in the valley becomes colder as it ascends the sides of the mountain. The diminishing pressure allows the air to expand and store away its heat. It is, therefore, not the snow on the top of mountains which cools the air, but it is the rarity of the air which keeps the snow itself from melting. As a general law, the decrease of temperature amounts to 1° Fahrenheit for every 300 feet in perpendicular height.

A variation in the amount of heat affects the volume of a gas as sensibly as a variation in the pressure. An addition of heat increases the repulsive force of the atoms, and thus expands the volume. All gases, reckoning from the freezing point of water, expand nearly the 480th part of their bulk for every degree of temperature; or, in other words, if one cubic foot of air had its temperature raised 480° above the freezing point, its elastic force would be doubled, or it would tend to expand to twice its former bulk.

If a number of atoms of air in the lower stratum receives a greater amount of heat than those in the vicinity, they will repel each other to a greater distance apart than they were before they were heated, and will have a tendency to ascend, on the same principle that a piece of cork rises in water.

On these undisputed data Dalton founded his two famous conditions of atmospheric equilibrium, which are now regarded as the true basis on which all atmospheric disturbances are to be studied. First, that the atmosphere can only remain in a state of rest or equilibrium when the barometer stands at the same height at the level of the sea in all parts of the globe, because the aerial envelope has a tendency like water to seek its equilibrium. Second, that the atmosphere must every where have the same temperature at the level of the sea, and that its various strata as we ascend must have a temperature corresponding to their position—that is, that every atom, from the top to the bottom of the atmosphere, must possess the same absolute amount of heat.

A number of natural agencies are at work to disturb the equilibrium of the atmosphere, and to give rise to aerial currents; among them the most important is the difference of temperature in different parts of the earth. The air within the tropics, constantly heated by the rays of an almost perpendicular sun, is rendered lighter, and is pushed upward by the heavier air north and south of this region. A current in this direction from each pole is thus produced at the surface of the earth, while an opposite current towards each pole is generated by the rarefied air which rises above the heated belt, and flows backward like water seeking its equilibrium. These currents, on account of the rotation of the earth, are not along the meridian, but those at the surface take a westerly direction, while those above flow in an easterly course. This is the origin of the trade winds at the surface of the earth, and of the great westerly current which is almost constantly moving in the upper strata over the middle and northern portions of the United States. That such a current does prevail over the regions mentioned is clearly proved by Professor Coffin's admirable report on the winds of the northern hemisphere, published in the Smithsonian Contributions to Knowledge. The phenomenon of the constancy of this upper current early attracted my notice in my tour through this country, and I learn from the records that it is the same all the year. The fact of the existence of this current is referred to by President Dwight, in his History of New England, to explain some atmospheric phenomena; and, indeed, it is one of the keys to a knowledge of the peculiarities of the meteorology of this country.

To understand some of the peculiar actions which occur in the lower strata of the atmosphere, it is necessary for us to consider a little more attentively the effect which sometimes takes place when a large area is slowly heated and the air above it gradually expanded. In this case the heated air, increasing its volume and resting on the surface of the earth, pushes up the air above it, and thus retains it in a state of unstable equilibrium. This condition was observed by the French savans as existing over the heated sand of the desert, and giving rise to the mirage. It was also observed by Colonel Sykes, on the plains of Hindostan, and is quite common in all latitudes.

This is a very unstable condition of the atmosphere, and is constantly liable to be overturned; yet its philosophy is not difficult to comprehend. When the atoms of air in the lower stratum are gradually and equally heated, all have a tendency to rise, and the cold atoms above have a tendency to descend. But as there is not room for all to descend and all to ascend at the same time, there is little downward or upward motion.

This is a very simple principle, but it is the only one which enables us to comprehend how a dead calm often exists immediately before violent storms, and even before the tremendous hurricanes of the West India islands. A large amount of power is in this way held in reserve ready to be developed under various circumstances. We shall mention some phenomena as illustrations which are produced in this way.

The unstable condition of the air, which results from the undue heat of the lower stratum, produces those great whirlwinds of dust and sand in the deserts of Arabia and Africa. The air flows in beneath, and revolves as it ascends, carrying loose material with it. Humboldt, when crossing over the great plains of South America during the hot season, recorded a curious instance of the effect of the sun's rays on the surface of the ground when the air was calm: "In the Mesa de Paja," says that illustrious traveller, "we entered the basin of the Llanos. The sun was almost at its zenith; the earth, wherever it appeared sterile and destitute of vegetation, was at the temperature of 86° to 90° F.; not a breath of wind was felt at the height at which we were on our mules; yet in the midst of this apparent calm whirls of dust incessantly arose, driven on by these small currents of air which glide only over the surface of the ground, and are occasioned by the difference of temperature between the naked sand and the spots covered with grass."—(Personal Narrative, Vol. 1.) The land and the sea breezes observed in warm countries are caused by somewhat similar agencies. The land in the day time becomes heated to a much greater degree than the sea; the air over the former expands and flows away above, while the comparatively cold air from the sea rushes over the land. This is exactly reversed at night, the air over the sea being slightly warmer than over the land—the breeze is from the latter. All are agreed as to the general cause of this phenomenon, but I am inclined to think the particular mode of action has not received that attention which it deserves. As I shall have occasion to show that the action of the sea breeze in Great Britain apparently furnishes us with the true principle upon which certain violent disturbances sometimes take place over one half of Europe, I shall be a little particular in describing the exact mode of action. And I am not singular in opinion that a modification of the same principle applies to some of the storms of the United States. On a recent visit to Cuba I had an opportunity to study some well defined instances of land and sea breezes. I was particularly interested in the former, because I was less familiar with them from personal observation; for while the sea breeze is common in summer on the east coast of Scotland, the land breeze is very rare. Hugh Miller has given a description of the sea breeze in his work entitled "My School and Schoolmasters," as it occurs on the Cromarty coast, which is well worth a perusal by those who take an interest in such matters.

The particular summer sea breeze of North Britain, so far as I have had an opportunity of observing, only occurs when an upper current is flowing from a westerly quarter. This condition seems to be essential to its action. The breeze is always strongest on the coast, it gradually moderates as it passes into the interior, and finally dies away long before it reaches the west coast. The manner in which the sea breeze loses its force shows that it is gradually absorbed into the upper current, and that it does not rise in one vertical column, but that there is a constant ascension and absorption going on over the whole extent agitated by the breeze. By way of exemplification, and to render my exposition more clear, I shall direct your attention to the action which takes place between soft and salt water, at the mouths of large rivers. Captain King observed a current of salt water running up the mouth of the Santa Cruz, beneath the fresh water. In this case we cannot for a moment imagine that the salt water rises in a body at any particular spot, and returns as salt water to the sea; but only that the salt under current is gradually absorbed into the fresh stream above, at every point as far as the salt water extends.

Now suppose the sea breeze has a depth of 2,000 feet, and extends 50 miles into the interior of the country; it will not rise in a vertical column of 2,000 feet in width, but will be gradually absorbed, by rising in small portions into the upper current along the whole distance traversed. The greater depth of salt water at the mouth of the river corresponds to the greater velocity of the air on reaching the land. The spot where the breeze is not felt has its counterpart in that point of the bed of the river where the salt water ceases to flow against the stream. The deep upper current from the southwest, which overlies the shallow sea breeze, performs the part of the large body of fresh water of the river, to which the other phenomena are merely secondary. The power which propels the salt water up the bed of the river is the difference in the weight of the fresh and salt water. In the sea breeze, the air over the surface of the land is lighter than that over the sea at the same elevation; and it is this difference in the weight of the two columns of air which, in this case, is the propelling power. If the barometer was sufficiently delicate, the rate of motion of the breeze might be calculated with considerable precision.

The heat of the sun materially affects the force of the winds at the earth's surface in all parts of the world. The still air of evening is well known to be in striking contrast with the breeze of midday. During the night the air cools more rapidly next the ground than at a greater elevation. The ascending currents cease with the heat of the sun, and friction soon induces a calm.

At the meeting of the British Association for the Advancement of Science the year before last, I took occasion, in illustrating the action of one class of storms which agitate the atmosphere of Europe, to point out the fact that the sun, during the summer months, in North Britain, had the effect to reverse the motion of a thin stratum of air at the surface of the ground; while, *during the day*, a north current constantly flowed above and a south current flowed below, *during the night* the latter was reversed. I have found similar phenomena to prevail in the United States. For some days, in Charleston, last January, I observed that the wind was south during the heat of the day, and north in the morning. I cannot stop now to discuss the cause of this phenomenon, though it is exceedingly interesting in a scientific point of view. But there is an analogous effect produced, upon a grand scale, east of the Rocky mountains, over the United States, as well as the British Possessions, that requires to be noticed in this place. It has been most satisfactorily made out by Professor Coffin, that southerly winds, in North America, are much more common in summer than in winter; the following are his reductions:

Between lat. 32° and 33°, 9 stations, 8 year's average: S. Carolina, Georgia, Alabama, and Mississippi.	Jan.,	N. winds, 3.06. —	S. to W.S.W. 7.77 days.
	July,	N. winds, 1.83. —	S. to W.S.W. 10.16 days
Delaware, Maryland, and Eastern Virginia.	Jan.,	N. winds, 2.81. —	S. to W.S.W. 6.29 days.
	July,	N. winds, 1.05 —	S. to W.S.W. 13.00 days.
New England States south of latitude 45°, 49 stations, 5 years.	Jan.,	N. winds, 3.55. —	S. to W.S.W. 6.60 days.
	July,	N. winds, 1.44. —	S. to W.S.W. 15.74 days.
Between 45° and 50° latitude: Iowa, Wisconsin, Michigan, Canada, and Maine, 10 stations, 17 years.	Jan.,	N. winds, 4.17. —	S. to W.S.W. 5.73 days.
	July,	N. winds, 1.83. —	S. to W.S.W. 10.77 days.
Total north wind		19.74	Total south wind. 76.06

I quite concur in the opinion, first entertained by Volney, that the summer south winds of the United States are chiefly supplied from the trade winds of the tropics. To this wind is to be ascribed the amazing fertility of the climate for sugar, cotton, Indian corn, and tobacco. The isthmus which connects North and South America is too high to allow the trade winds to cross into the Pacific ocean; and in summer they appear to be frequently directed northwards by this great natural wall, and find their way across the Gulf of Mexico, and spread out as a surface current loaded with moisture over the Mississippi valley and the eastern seaboard States. If the isthmus which connects the two continents had been sufficiently low to allow the trade winds to cross into the Pacific, the valley of the Mississippi would have had, in all probability, a much less productive summer climate, resembling that of the south of Europe or the north of Africa.

I may here mention that there is only an extremely limited area in Europe which has sufficient summer rains, with the requisite temperature, to grow Indian corn, and that there are no cotton or sugar regions. The summers of Spain, except on the northwest of the country, are usually so very dry that little Indian corn can be grown without artificial watering. The productive powers of the soil are almost entirely centred in the valleys, which are irrigated by the melting of the snow of the mountains.

The summers of Italy are also too dry, and the melting of the snow on the Alps is essential to the fertility of Lombardy. The largest and best region for Indian corn in Europe is in the south and east of France. Mr. Marsh, in his introductory lecture here, told us that for three months rain did not fall in summer at Constantinople. In Palestine, "rain in summer" is still as rare as the "snow in harvest." In the valley of the lower Nile, a shower of rain is a remarkable phenomenon; the overflowings of the river serve for the growth of wheat, but no Indian corn or millet can be had without laborious irrigation: accordingly, fifty thousand oxen are employed in summer to draw water for this purpose. In upper Egypt no crops of any kind are obtained without the same appliance; and during a low current in the river the peasants are obliged to raise the water upwards of forty feet. When we reflect on these facts, the great fertility of the summer climate of North America, east of the Rocky Mountains, is very surprising. The aridity of the Mediterranean shores is owing to the prevalence of northerly winds; while the fertility of the United States is owing to the prevalence of those from the south. This statement is amply supported by Professor Coffin's researches in the Smithsonian Contributions.

The warm surface wind which sets in from the Gulf of Mexico over the United States, is not only the great source of fertility, but is also the great disturbing element of the atmosphere at all seasons of the year. During the warm season, in this country, when the wind changes to north or northwest, the sky becomes peculiarly transparent and blue in color. I have frequently had occasion, in my tour through Canada and the United States, to observe that the lower south and southwest wind begins to blow, as in Great Britain, shortly after the sun heats the air at the surface of the ground, and that the sky soon loses its peculiar transparency. One point in regard to this surface wind from the south deserves special notice. I allude to the fact that it is often at rest or very sluggish during the night, and most active during the maximum heat of the day. This vast surface wind which spreads over the region east of the Rocky Mountains, and over the Gulf of Mexico, is therefore daily put put in motion by the heat of the sun. The short time which I have been able to devote to this subject leads me to believe that the breeze begins to stir at an earlier hour in the day in the higher latitudes, and that it is gradually propagated to the south. The sun rising earlier the farther we advance northward is probably the cause of this phenomenon.

Mr. Thom, in his work on the "Nature and Course of Storms," p. 255, informs us that south and southwest winds prevail during summer over the projecting shoulder of South America, at Guiana; and I was informed by the sugar-planters that in Cuba south winds are common during the rainy season, namely, May, June, July, and August. Mr. Phelps, also, in a recent communication to the meteorological department of the Smithsonian Institution, mentions the fact that at Fort Brown, on the Rio Grande, the prevailing winds are from the south, or probably a point or *two* to the east of south. This, he says, is more particularly the case during spring and the earlier part of summer, when they are usually pretty constant, especially during the day time, blowing at the rate of fourteen miles an hour, or five degrees of latitude per day. But Professor Coffin's report, already alluded to, gives us the best view of this great aerial current, which flows over the Mississippi valley, as well as along the Atlantic slope.

The two great systems of atmospheric currents, viz: the lower and warm surface wind from the south, and the cold and dry current flowing constantly in the upper regions from the west, are intimately associated with all the changes of the weather in the United States. But before we attempt to trace the nature of these changes we must direct attention to another element of meteorology, which we have as yet almost left out of view, viz: the elastic and invisible vapor of water contained in the air, and which plays so important a part in almost all atmospheric changes.

Science, as we have seen, was long perplexed with the problem of the manner in which water existed in the air; sometimes entirely invisible, at others obscuring the heavens with clouds, or falling as rain or snow. For the solution of this question, we are also indebted to John Dalton, who gave an explanation of the matter, no less simple than consistent and ingenious. He at the same time opened up a new view of the mechanism of mixed gases, gave us new ideas of the constitution of the atmosphere, and enabled us to comprehend the agency which "divides the waters of the firmament from the fountains of the deep." The hygrometry of the atmosphere will be considered in our next lecture.

METEOROLOGY.

Second Lecture.

That water placed in an open vessel over a fire does not have its temperature raised above 212 degrees, however great the heat may be, and that the steam produced is no warmer, is among the first of the wonders which arrests the attention of the student entering upon the field of physical science. The heat of the fire is absorbed in the production of the steam. The atoms of water are made to repel each other. A cubic inch of this liquid converted into steam at 212 degrees, at the ordinary pressure of the atmosphere, has its bulk increased nearly 1,700 times. The elasticity of the steam thus produced is equal to the weight of a perpendicular column of 30 inches of mercury. This must appear quite evident when we consider how steam is formed. It rises from the bottom of the vessel which contains the water, in bubbles, and can only be rapidly formed when the repulsion of the atoms is able to resist the whole weight of the incumbent atmosphere.

Dalton, however, discovered that vapor is formed at all temperatures; that the boiling point of water and the elasticity of the vapor are entirely regulated by heat and pressure. This he proved by allowing a small quantity of water to ascend to the top of the mercury in a common barometer tube, where it produced vapor, the elasticity or pressure of which could be exactly measured by the height of the column, as the heat was increased or diminished. This simple experiment showed that the connexion between the temperature, density, and elasticity of steam is subject to the same physical law which regulates the density and elasticity of the permanent gases. The following exhibits a few cases of steam at different temperatures, with the corresponding force and weight:

Temp. 0°;	force	0.068	in inches;	weight of cubic foot,	0.856	grains.
20°	“	0.140	“	“	1.688	“
40°	“	0.280	“	“	3.239	“
60°	“	0.560	“	“	6.222	“
80°	“	1.060	“	“	11.333	“
212°	“	30. 00	“	“	257.218	“

In fact, after allowing for the difference of the temperature in steam, according to the law which holds in reference to other gases, the pressure of steam at any low temperature being given, the weight of a cubic foot of steam can be calculated by the simple rule of proportion.

Steam or vapor, at all temperatures, may be considered as water containing a definite amount of heat. A pound of steam at 212° contains very little more caloric than a pound of vapor at 32°. This is proved by the fact that steam, at any temperature, when condensed, is capable of raising the temperature of its own weight of water more than 1,000°. If a cubic foot of steam at 32°, weighing 2.539 grains, were subjected to pressure, and none of the heat evolved during the condensation lost, a small volume of steam at 212° would be produced. But a cubic foot of steam at 32° could not exist in the atmosphere by itself, as it would be subjected to a pressure of 30 inches of mercury, whereas it could bear no more than one-fifth of an inch. Hence a difficulty arose amongst chemists in regard to the manner in which water existed in the invisible form in the atmosphere at all temperatures, and under all pressures. There was also some difficulty in accounting for the manner in which the mixture of the different gases took place.

It has been found that air brought down from the tops of the highest mountains, and from the greatest elevation reached by aeronauts, is nearly the same in composition as at the surface of the earth. This fact was rather perplexing, because the different gases of the atmosphere have not the same specific gravity. A cubic foot of oxygen weighed more than one of nitrogen, while one of carbonic acid was 50 per cent. heavier than either.

Common air	1.0000
Carbonic acid	1.5240
Nitrogen	0.9760
Oxygen	1.1026
Steam 212°	0.6235

The carbonic acid being the heaviest gas, it should chiefly occupy the lower stratum of the atmosphere; and the nitrogen the top. Dalton, to reconcile a variety of phenomena with each other, added a new proposition to the theory of the atomic constitution of the mixed gases—namely, that the atoms of oxygen do not repel the atoms of nitrogen, but only those of their own kind. That the one gas is as a vacuum to the other. On this principle the most complete mixture of gases is explained, the atoms of one gas by their mutual repulsion are forced apart as is in void space, and thus diffused among those of another. At the last lecture we mentioned that if this room were completely exhausted of air, and a cubic inch of hydrogen introduced, it would instantly expand and fill the whole space. Now, the same thing would happen if a cubic inch of hydrogen were introduced into the room filled with air. The process would be much slower, but the mutual repulsion of the atoms of hydrogen would still be in as active operation as it was in the vacuum, and would still cause them to separate until they pressed against the walls of the room with as much force as if there were no air in it.

Not only has the truth of this law been verified, but the diffusive velocity of the various gases ascertained by actual measurement. This velocity is inversely as the density of the gases; in other words, the lighter the gas the greater its rapidity of diffusion. The vapor of water, or steam, is subject to the same law; and this is the solution of the difficulty we mentioned as to its capability of existing in the atmosphere at all temperatures. In accordance with this law, the atoms of water, as well as those of the several gases which compose the atmosphere, are as far separate from the atoms of their own kind as they would be if each alone occupied the space. The pressure of the compound atmosphere is therefore made up of the joint pressures of the individual gases.

Strictly speaking, vapor is not condensed by the pressure of air, but by diminution of temperature; and the amount of moisture which can exist at any time in the atmosphere depends upon the amount of heat. Air saturated with moisture may be likened to a vessel filled with round shot or sand. The spaces between the atoms of the permanent gases are occupied by the atoms of steam, in the same way as water fills up the vacant spaces between the shot or sand. The atoms of water are at a distance when steam at any temperature is by itself, and they can possess no greater repulsive force than is due to the temperature of the evaporating surface. Pressure applied to the atoms will cause condensation, if the heat arising from this act is lost. This is the same in the moistest atmosphere—the atoms of water are at a distance, and their repulsive or diffusive force is the cause of their remaining invisible. Evaporation, therefore, in the atmosphere at a given temperature, can only take place when the atoms of water are removed as far from those on the evaporating surface as they would be in pure steam at the same given temperature.

Air is said to be saturated with moisture when as many atoms of vapor are contained in it as would exist in a vacuum at the same temperature. The atoms of air merely fill up the interstices of the elastic vapor of water, or the converse. If the temperature be diminished, the repulsion of the atoms will not be sufficient to support so great a pressure, and a part of the vapor will be condensed into water. The reduced temperature at which this condensation begins to take place is called the dew point, or point of precipitation.

The elastic force of vapor would ultimately cause it to rise to the top of the atmosphere by virtue of this repulsive or diffusive property, if it were not checked by other causes. At one time meteorologists attributed many atmospheric phenomena to the great activity of the diffusive power of the vapor of water; but we are indebted to Professor Espy for showing that this has been very much overrated, and other agents are the more active causes.

The air has its temperature raised during the day by the direct heat from the sun and contact with the earth, and loses the greater part of this heat during the night by radiation into space. The ground radiating heat much faster than air in a clear, calm night, is generally cooled down below the point of precipitation of the vapor, and thus condensation of moisture is produced and dew formed. This effect of radiation has a most beneficial influence on vegetation. The formation of dew is regulated by a very simple law, viz: that *the dewed surface is always colder than the air in contact with it.* In the same way the dew-point of the air is ascertained by cooling down any body until moisture is formed upon it. Several hygrometers have been formed on this principle.

The amount of moisture in the atmosphere has a great influence in modifying the heating power of the sun's rays, as well as in the radiation of heat during the night into space. We often find two days in summer equally free from clouds and equally calm, while the one may be oppressively warm, and the other comparatively cool. This does not arise from a difference in the power of the sun's rays, but from the quantity of moisture in the atmosphere.

The influence of moisture in tempering the sun's rays is a remarkable fact and well worthy of further investigation. When the dew point is high, or, in other words, when the air is filled with moisture, the radiation from the earth is prevented, and the temperature of the night remains almost as high as that of the day; when the dew point is low, the sun's rays pass, without absorption, to the earth, and impart little of their heat directly to the air. The medium dew points are, therefore, most favorable to extreme heat in the atmosphere, and the greater heat beyond the tropics is probably owing to this cause.

The fact that the amount of moisture in the air regulates the temperature of the nights has not received the attention which it deserves. I shall hereafter show that the hygrometrical condition of the atmophere throws a very considerable amount of light on the action of North American and European storms; and therefore I am more anxious to draw your particular attention to the relation between the dew point of the vapor of the air and the night temperatures, because this is the only means which I have of indicating the hygrometrical conditions connected with the storms of the United States.

It seems to be a law which holds in general over the world that the temperature of the air at sunrise during calm nights, at a certain distance from the ground, falls a little below the dew point of the air during the preceding day. The mean temperature of the air at sunrise, therefore, approximates very closely to the mean dew point. The great amount of moisture in the air within the tropics is the cause of the warm and brilliant nights. Radiation from the air and ground, under these conditions, seems to lose its power. On the other hand, travellers in all parts of the world inform us, incidentally, as to the connection between dry air and cold nights. Mr. Inglis, in his travels through Spain, relates that he was oppressed by the hot rays of the sun in the valley of Granada while the hoar frost was lying white in the shade. Eastern travellers in the deserts often complain of the broiling heat of the air during the day, and of its chill temperature at night. Beautiful allusions to the same law are also found in Scripture; many of you will recollect that one of the greatest hardships which Jacob experienced while he tended Laban's flocks was, that through the "drought by day and the frosts by night sleep departed from his eyes." On the other hand, the moisture from the Atlantic in summer allows the air to retain its heat in the valley of Chamouni, in Switzerland, so that grapes ripen in the immediate proximity of the glaciers which descend from the Alps. At Bergen, in Norway, the same element allows the cherry-tree to mature its fruit where you can pluck it and throw the stones upon the broad mass of ice which slowly descends from the mountains.

Those days during summer in the United States on which the sky is very transparent are rather deficient in moisture. The air is then somewhat bracing, as the sun does not have the power of heating it up to a high degree. The great changes in the weather which take place at all seasons over the United States, and the very cold winters in comparision to those of Europe, are intimately associated with the hygrometric condition of the atmosphere, which we must now consider.

Why are the winters so cold at Washington in the 38° of latitude, the same as that of Lisbon, in Portugal, where the orange-trees are now in blossom? This is owing to the great prevalence of west and northwest winds, which are very dry, and sweep over the vast territory from Canada to Florida, and are converted into the northern of Cuba and the coast along the Gulf of Mexico. President Dwight, a most accurate observer, in his Travels and History of New England describes the character and effect of the winds so accurately, that I will quote two short passages. He says, "In 1787 the west wind began to blow about the 20th November, and continued its progress with only four short interruptions until the 20th of the following March—somewhat more than 100 days. During the whole time the weather for the season was very cold." Also, "in 1780 the wind blew from the west more than six weeks without any intermission, and during the whole of this time the weather was so cold that snow did not dissolve sufficiently to give drops from the southern eaves of houses." So long as the westerly wind continues to blow in winter there is no cessation of your cold, and so long as it continues to flow in a broad regular stream in summer there is no end to your drought. President Dwight maintains that the west and northwest wind is merely the descent of the upper current which flows so regularly right across the Rocky Mountains. Whoever will take the trouble to examine the meteorological observations within the Smithsonian Institution, I am inclined to think, will come to the same conclusion. If the south wind was as common in winter as in summer, and if there was no descent of this upper current, your winters might be as mild as those of Portugal, which are tempered by the moist wind from the southern Atlantic.

The question naturally arises, why is the west wind so extremely cold? The answer is, simply, because in crossing the Rocky Mountains it is robbed of its moisture; and becoming so dry that the sun pours down his rays of heat; in vain neither the air by day nor the ground by night can retain them; they fly off into space. The principle on which air is dried in passing over high mountains is a very simple one, if we merely bear in mind that air expands under diminished pressure and becomes colder by the heat being diffused over a greater space. Professor Espy has very ably investigated this subject on theoretical grounds. But, as our space is exceedingly limited, I shall merely adduce some examples by way of illustration. Mr. Walsh made an ascent in a balloon on the 26th August, 1852, from Kew Gardens, in England. The barometer stood at 30 inches, and the dew point was 61°; or, in other words, the air contained 6,06 grains of water in every cubic foot. At the height of 18,370 feet the barometer stood at 15 inches, temperature of air 70, dew point 2°8, or equivalent to 0.8 grain of water in a cubic foot. But at this elevation the air being expanded by the diminished pressure, two cubic feet will only weigh about as much as one did at the surface of the earth. Two cubic feet, therefore, would contain 1.6 grains of water. Now, it will be evident, if this upper air was to descend to the surface of the earth, it would have its temperature raised by coming under increased pressure; but its dew point, as will be seen by inspecting a table, would be no higher than 23°, instead of 61°; the radiation during one night would, therefore, cool down the air at the surface of the earth to this temperature. The dry upper current coming over the Rocky Mountains often descends to the earth in winter, and is the cause of the severe weather at that season in the country east of these mountains. The great westerly current of air from the Pacific in passing over the Rocky Mountains, and in ascending their westerly slopes, becomes colder by expansion, and, consequently, deposits its moisture. It is true the heat liberated by the condensation of the vapor will tend to elevate the temperature of the air on the top and at the foot of the mountain above its nominal point; but this effect is counteracted, as we have said, by the increased freedom the dry air gives to the radiation of heat from the surface of the earth and the lower stratum of air, particularly when it is spread over a wide extent of radiating surface. The descent, therefore, of the dry and upper current of westerly winds to the surface of the earth is, I think, the principal cause of the sudden and extreme changes of weather in this clime. President Dwight states that in the month of July, 1804, considerable snow fell at Salem, in New England, and that a severe frost was experienced in different parts of the same country. In all parts of the world where moist winds, or those from the ocean, blow over high ranges of mountains, they deposit their moisture in the form of rain and snow on the windward slopes. This is the case on the coast range of Oregon and California, and also on the slopes opposite the prevailing moist winds in South America.

In England not more than 23 inches of water falls annually in some of the level eastern counties during the year, while nearly 200 inches occasionally fall on the western side of the mountains of Cumberland. The west wisds of Norway are remarkably mild and rainy for such a high latitude, while the same winds in Sweden are comparatively cold; the air, in losing its moisture on the high chain of mountains, loses its power of retaining the large amount of latent heat extricated by the condensation of vapor.

The production of cold through expansion is the cause of clouds resting on the tops of mountains when they should apparently be borne away on the breeze. The precipitation of vapor as the air rises on the one side, and the evaporation of it as the air descends on the other, is the true cause of the phenomenon. The formation of clouds in the sky and precipitation of moisture are chiefly produced, as Mr. Espy has demonstrated, by the ascent of comparatively moist and warm air from below. The expansion produces cold, and of course the precipitation of moisture into clouds and rain. The cumulus clouds of summer are thus formed by ascending currents of moist air. The condensation of the vapor extricates a large amount of latent heat, which expands the air within the cloud, and thus produces an increased buoyancy. Before thunder-storms the air is usually moist and oppressive, the perspiration from the skin is checked by the moisture, and feels warmer on this account than it really is. The temperature within this cloud being higher than that on the outside in consequence of the evolution of latent heat, the passage of a thunder-cloud over any place almost invariably disturbs the air at the surface of the ground. The extrication of heat is a motive power which constantly causes the air to ascend in the front of the storm as the cloud drifts along in the upper current. Squalls are produced in the same way. Professor Espy, in his Report on Meteorology, says: "Low clouds are constantly forming in the front of squalls by the upward motion of the moist air as fast as their hinder parts are swept down by the falling rain, and thus they appear constantly just in front of the squall, for it is only in front that there is an up-moving column of air from below."

We shall enter a little more particularly into this subject, to show the analogy between these isolated disturbances arising from the formation of cloud and precipitation of rain and the land and sea breezes, hurricanes of the West India islands, thunder storms of America and Europe, and also some of the great snow and rain storms of both continents.

In Humboldt's celebrated voyage from Europe to South America he relates that, on reaching the latitudes of the trades, the "wind fell gradually the further we receded from the African coast; it was sometimes smooth water for several hours, and these short calms were regularly interrupted. Black, thick clouds, marked by strong outlines, rose in the east, and it seemed as if a squall would have forced us to haul our top-sails; but the breeze freshened anew, there fell large drops of rain, and the storm dispersed. Meanwhile it was curious to observe the effects of several black, isolated, and very low clouds which passed the zenith. We felt the force of the wind augment or diminish progressively according as small bodies of vesicular vapor approached or receded. It is by the help of these squalls, which alternate with dead calms, that the passage from the Canary islands to the Antilles or southern coast of America is made in the months of June and July."

From this description we gather that there was an upper current prevailing from the east, in which the clouds drifted, bearing them over the calm air resting on the ocean. The air in front of the cloud is disturbed as soon as the cloud approaches, and a violent squall prevails so long as it is overhead. This shows the intimate connexion between the upper and lower currents of the atmosphere when clouds are passing.

Unless clouds were constantly replenished by vapor from below, it is physically impossible that they could continue to throw down such great quantities of rain over long tracts of country as they are sometimes known to do. At no time, even within the tropics, is the air over one spot capable of precipitating more than three inches of rain.

In the squalls described by Humboldt we observe that there was calm both before and after the passage of the cloud. The motion of the air at the surface of the sea is much the same as if the whole portion of it under the cloud were in a state of vertical rotation around a horizontal axis. You will perceive that there is a resemblance in the motion of the air under isolated storm-clouds to that of the air in land

and sea breezes. The latent caloric evolved by the condensation of vapor is the moving power in this class of phenomena, and the difference between the temperature of the land and the sea is the disturbing force in the other. I have frequently attempted to show that many of the European storms were to be ascribed to a modification of these principles. Since reaching Washington it has been pointed out to me by Professor Henry that Professor Mitchell, of North Carolina, gave in Silliman's Journal a similar explanation of some of the American storms as far back as 1831. I had never seen this paper, and was a little surprised to find so great a similarity in our views, more especially as he had actually selected the same passages I have quoted from Humboldt as a common starting-point. But I have since found that Volney more than half a century ago accounts for one American snowstorm on the same principle.

I must, in the first place, draw your attention to a feature which appears to be common to the hurricanes of the West India Islands, and to the local squalls in the region of the trade winds, viz: that there is usually a calm before these terrific disturbances of the atmosphere. All who have examined these meteors are of opinion that the current above is from the southeast, and bears the hurricane clouds over the still and highly heated air; this being surcharged with moisture is in a most unstable state of equilibrium, which is liable to be overturned by the slightest cause that conspires to produce an up-moving volumn of air. To illustrate this I will merely read to you Captain Marryatt's graphic description of the coming on of a West Indian hurricane as given in "Peter Simple:" "What a hot day this has been; not a cat's paw upon the water, and the sky all of a mist. Only look at the sun, how he goes down, puffed out to three times his size, as if he were in a terrible passion. I suspect we shall have a land breeze off strong. The heat was excessive and unaccountable, not the slightest breath of wind moved in the heavens or below; no clouds to be seen, and the stars were obscured by a sort of mist: there appeared a total stagnation in the elements. We had not pulled long before a low moaning was heard in the atmosphere, now here, now there, and we appeared to be pulling through solid darkness; I looked, and dark as it was, it appeared as if a sort of black wall was sweeping along right towards us. The moaning gradually increased to a stunning roar, and then at once it broke upon us with a noise to which no thunder can bear comparison. The sea was perfectly level, but boiling and covered with a white foam, so that we appeared in the night to be floating on milk."

Professor Mitchell, in the paper to which I have already referred, expresses the opinion that thunder storms must be much less grand and imposing in Europe than in America, because poets have not considered them worthy of particular attention. Shakspeare, however, has not neglected our thunder storms, and with his usual philosophical discrimination has portrayed some of their more important peculiarities:

> "We often see, against some storm,
> A silence in the heavens, the rack stand still,
> The bold winds speechless, and the orb below
> As hush as death: anon the dreadful thunder
> Doth rend the region."—*Hamlet.*

The formation and progress of thunder storms are very peculiar in this country. We have already alluded to the frequency of south and southwest winds over the United States in summer. These currents, derived, as we have said, from the trade winds of the tropics, contain a large amount of moisture, and are the source of the great fertility of the Mississippi valley. Extensive rains and thunder storms only occur after the south wind has prevailed for some time. I am inclined to believe that this vast aerial current, which flows below the upper westerly current, is much deeper in the southern than in the northern States. Mr. Phelps's observations, near the mouth of the Rio Grande, show that in his district the thunder clouds drift in the southeast current; and I have been informed that they follow the same direction in Louisiana and Alabama. But in the higher latitudes, as for example that of Washington, the thunder clouds all move in the direction of the upper current from a point or two north or south of west. The moisture which forms these clouds is no doubt derived from the lower stratum, whose upper surface is exposed to the erosion of the upper current, constantly sweeping a portion away towards the Atlantic. The action of the lower moist current rising into the upper and forming cloud, and perhaps part of the upper descending, is no doubt the principal propelling power of the surface wind. President Dwight gives a very good description of the thunder storms of New England, and refers to points which should be specially borne in mind. On one occasion he says: "The meridional line upon which I stood was crossed by the storm several miles to the south. During the whole day the wind had blown from the south, and continued to blow in the same direction on the surface throughout the afternoon, without a moment's intermission. But had the wind," says he, "which carried the cloud when it passed over the meridian swept the surface, the wind for a time, at least, must have been entirely stopped. This, however, was not the fact even for a moment." On another occasion, in 1809, a "thunder storm passed over New Haven, from the northwest, with great rapidity. It continued, as I judge, from an hour to an hour and a half. But though the clouds moved rapidly to the *southeast*, a *southwest* wind blew the whole of that day and *while the thunder storm was overhead with great violence*."

The increase in the strength of the southwest wind, as the clouds drifted overhead from the northwest, shows that the lower and upper currents mixed together; that as in the case of the squall mentioned by Humboldt, a part of the lower stratum of air rising formed cloud, and that a part of the upper stratum descending to the earth was carried away by the prevailing surface wind from the southwest. This propelling power, I think, cannot be doubted in thunder storms; but I imagine the same principle must be taken into account as a source of motion to the southwest surface winds whenever clouds form in the sky and drift in the upper current. Thunder squalls drifting from the west, as I am also informed by Professor Espy, often draw in the stratum of air from the east immediately above the earth's surface; while the falling rain under the clouds forces the air outwards towards the east, and it rises immediately before the rain, carrying up dust and other materials. A slight westerly breeze then usually springs up and follows the cloud just a little in the rear.

In fact, from the very irregular nature of the winds of the lower stratum, we must in general look for a local cause of propulsion, on the same principle that the motion of the air at the surface of the earth, during the day in summer, with clear and dry weather, is constantly varied by the heat of the sun at every spot over which the breeze passes. As soon as the warm southerly wind begins to blow as a general surface current over the United States, the conditions necessary to the production of a storm already exist. The southerly wind, often veering about very irregularly, will then frequently continue in the same direction, until the whole country from the Gulf of Mexico to Canada is covered with a comparatively hot and moist stratum of air. Under these circumstances a crisis must ensue, when the upper current from the Rocky Mountains resumes its sway at the surface of the earth. In winter it often sweeps the stratum of moist air from over the United States into the Atlantic, and completely changes the character of the weather in a very short time. In summer the changes are generally much less marked; for Professor Coffin's researches show that the northerly winds then lose their power. At this season the process usually takes place in a gradual manner. Thunder clouds, drifting in the upper current, as described by Professor Dwight, shower down their watery contents over the land, and thus enable Indian corn to be successfully cultivated over a surface of country vastly greater than in any other part of the world. How these effects are brought about, involves the whole question of the action of storms east of the Rocky Mountains. We shall leave, however, the further discussion of this for the present, and conclude this lecture by one example, showing the scale upon which thunder storms are sometimes developed much about the same time over a vast area of country. I am only sorry that my time has not permitted me to analyze this storm in all its details.

During the first days of last September the wind was mostly from the south; the weather became excessively hot and oppressive; the newspapers in all parts of the country were recording the high temperatures; when, on the 6th, thunder storms took place nearly simultaneously in Iowa, Illinois, Indiana, Ohio, Pennsylvania, New York, East and West Canada, and the New England States. Large quantities of rain fell in various parts of the country, as the storms were in several places somewhat locally developed. At some points the northwest upper current reached the surface of the earth for a time, the southwest wind again blowing as before, until a general change of wind to the northwest prevailed, and caused a great fall in the temperature. At Saratoga the thermometer stood at 96° in the shade on the afternoon of the 6th, and at 46° on the morning of the 9th at Rochester. It is a fact worthy of attention that a severe storm, amounting to a hurricane, swept the southeastern coast of the United States just about the time that this great change was taking place in the north and west. It is certainly well worthy the investigation of American meteorologists to ascertain whether any connexion exists between the weather in the northwestern States and the hurricanes of the West Indian islands, for in this instance the coincidence of phenomena was quite remarkable. As will be seen from our next lecture, great changes occurring in the northwest are rapidly propagated to the southeast in the case of winter storms.

METEOROLOGY.

Third Lecture.

When northwest winds prevail over the United States in winter, the air is very dry and cold; so long as the wind remains in this quarter there is no termination to the cold weather. It does not moderate, at least the thermometer does not rise, until the moisture is increased. I suppose it is admitted by meteorologists that the cold spells of weather in the United States are first felt in the west and northwest, and gradually extend over the country to the southeast. This direction, it will be observed, corresponds very nearly with the course of the current, which is so constant in the upper stratum of the atmosphere in this region. But it is a curious fact, well worthy of the attention of meteorologists, that the warm and moist surface air which precedes storms and cold weather travels also from northwest to southeast; at all events, it apparently does so. Sometimes a belt of moist air, several hundred miles in breadth, and extending from the mouth of the Mississippi to the lakes, and probably much further north, seems to advance from the west, while there is very cold weather both behind and in front of it. The storms of February, 1842, described by Professor Loomis in the Transactions of the American Philosophical Society, were of this character. On the morning of the 10th November last, similar phenomena were presented: the eastern portion of the Mississippi valley, and all the States south of the lakes and west of the Alleghany range, were under the influence of a comparatively moist and warm stratum of air, at the very moment that the temperature was about 20° lower from latitude 35° to 45° on the Atlantic seaboard, and between the same parallel of latitude in the western States west of longitude 92°. By the night of the 10th November, the weather became very moist and warm in the Atlantic seaboard States, more so than it had been in Ohio the previous day.

The moisture which was found in the broad band could not originally have come from the west, northwest, or north, because these winds are always exceedingly dry; nor could it have come from the Atlantic ocean, because the weather remains cold on the coasts when it is much warmer in Ohio. Indeed the storm was at hand before the east wind set in, and this is a usual occurrence. There can be but little doubt, therefore, that this moisture is originally derived from the Gulf of Mexico, and that it is spread over the middle and eastern portion of the United States by the southerly current, which, as we have before remarked, is, in our opinion, a deflected portion of the trade winds.

In a former lecture, I pointed out the fact, abundantly proved by Professor Coffin, that these southerly winds prevail more in *summer* than in *winter;* and an important point here suggests itself for future discussion. I think it very probable that a broad band of southerly winds, extending across the country from Florida to Texas, may flow northward and gradually diffuse itself as a surface current over the valley of the Mississippi and the seaboard States. The sun heating the earth more at the north, during the longer days, assists in the propulsion of this current. The higher portions of this lower current are in contact with the under surface of the cold upper current from the west, and in the mingling of the two the moisture of the former is precipitated into clouds or rain. In some cases the lower current may thus be gradually absorbed into the upper one, and this action may take place over a considerable portion of the country, producing an extended cloudiness and perhaps a general fall of rain without violent atmospheric disturbance.

In winter, the propulsion of the southerly winds is not favored by the heat of the sun; at this season, therefore, they do not extend to so great a breadth as in summer, and only flow over the northern regions in streams, forming narrow belts of warm and moist air, to which we have just adverted. This warm current is often bounded by cold air, on the east and the west. The cold air on both sides is drifting from west to east, the warm current between (flowing from south and southwest) is also carried laterally to the east; and hence, the moist and warm weather of winter has an apparent motion from west to east.

Our inquiries relative to this point lead us to believe that the south and southwest winds in winter may begin to blow over Texas and the high ground a little to the east of the slopes of the Rocky Mountains, and cause a rise of temperature to the west of the Mississippi, when the northwest wind is still blowing dry, cold, and clear, over the whole of the middle and eastern States.

This, however, does not continue long; the west, northwest, and north winds soon descend between the western edge of the southern current and the mountains, and gradually force the former eastwards. On these occasions the north or northwest wind is the predominant one, which, rushing along the slopes of the mountains to the south, forms the well known northers from Vera Cruz to Cuba. According to this view, the norther should be felt sooner at the former place than at the latter. This much is certain, that almost every cold spell of weather which is experienced in the United States during winter is propagated to Cuba in the form of a norther, which, though the thermometer seldom sinks it below 55° at sunrise, is disagreeably felt by the inhabitants of the island.*

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* Since this lecture was written, I have had occasion to examine an interesting series of "Queries and Strictures," by Dr. Hare, in regard to Mr. Espy's Meteorological Report. The view which we have taken of the northers in the Gulf of Mexico will, as far as it goes, answer in the affirmative Dr. Hare's 20th query, page 5:

"Whether northers are not consequent to the displacement of the warmer air lying on the Gulf by the colder air of the territory of the United States north or northeast (northwest?) of the Gulf, to whatever cause that displacement may be due?"

Among the number of interesting points suggested by Dr. Hare for discussion, an answer to the following queries we consider would contribute much to the advancement of the meteorology of the United States:

"5th. Wherefore, in one of Mr. Espy's generalizations, he alleges that storms travel from *west* towards the east during the five winter months, instead of alleging that they travel from northwest to southeast, consistently with the observations of Loomis, above mentioned?"

"7th. Whether there is not another distinct kind of storm, long known and universally recognised as the 'northeaster,' or 'northeastern gale,' which has been distinguished from the southeaster, so called by its direction, its longer endurance, lesser violence, and by its not being usually followed, after a brief lull, by a northwester, nor any violent wind in a direction directly opposite to that in which it blew at the beginning of the storm?"

On no question has there been more discussion among meteorologists than that in regard to the cause of the fluctuations in the height of the barometer, especially during storms. John Dalton made the following remarks on this subject more than sixty years ago; and they are well worthy of consideration in the present day, particularly since we possess better opportunities of ascertaining their truth:

1. "The barometer," says Dalton, "has little variation within the tropics; while within the northern temperate zone, and doubtless within the southern also, its range increases in going from the equator. The mean annual range at Paris, for twenty years, was 1½ inches; the greatest range, or difference between the highest and lowest observations, for the same term, was 2 inches. At Kendal, the mean range for five years was 2.13 inches, the greatest range was 2.65 inches. In Sweden and Russia the range is still greater.

2. "In the temperate zones the range and fluctuations of the barometer are always greater in winter than in summer.

3. "The rise and fall of the barometer are not local, or confined to a small district of country, but extend over a considerable part of the globe, a space of two or three thousand miles in circuit, at least.

4. "It appears that the mean state of the barometer is rather lower than higher in winter than in summer, though a stratum of air on the earth's surface always weighs more in the former season than the latter.

5. "F. Laval made observations for ten days together upon the top of St. Pilen, a mountain near Marseilles, which is 960 yards high, and found that when the barometer varied 2¾ lines at Marseilles it varied 1¾ inches upon St. Pilen. Now had it been a law that the whole atmosphere rises and falls with the barometer, the fluctuations in any elevated barometer would be to those of another barometer below it nearly as the absolute heights of the mercurial column in each, which in these instances were far from being so. Hence, then, it may be inferred that the fluctuations of the barometer are occasioned chiefly by a variation in the density of the lower regions of the air, and not by an alternate elevation and depression of the whole superincumbent atmosphere."

I am quite aware that some of the deductions of Dalton require to be a little modified. His first proposition, however, that the range of the barometer increases in going from the equator towards the poles, is amply borne out as a general law by observations in this country as well as in Europe.

His fifth proposition is also correct, viz: that the fluctuations of the barometer are occasioned chiefly by a variation in the density of the lower regions of the air, and not by changes in the whole superincumbent atmosphere. To illustrate this, I will state a hypothetical case. In the balloon ascent made by Mr. Walsh, alluded to in a previous lecture, it was found that the barometer stood at 15 inches at the height of 18,370 feet. If the whole air below this elevation had been occupied by hydrogen gas, which is much lighter than common air, being only about one fifteenth of its weight at the same pressure, this lighter gas, possessing as much elasticity as common air, would be able to bear up the upper stratum of the atmosphere, weighing 15 inches of mercury; but at the surface of the earth the barometer would fall about 14 inches below its ordinary height. Now it is easily seen that if the warm and light wind from the southward, which blows with so much regularity in summer, were as light as hydrogen gas, with the same elasticity, it would cause an immense fall of the barometer along the whole of the Mississippi valley when it displaced the cold air which has come over the Rocky Mountains. The southerly winds from the Gulf of Mexico are much warmer and lighter than those which have poured down the eastern slopes of the Rocky Mountains, and been cooled by radiation on the plains to the east. Consequently when they displace these colder winds in the valley of the Mississippi, a fall of the barometer ought, to a certain extent, to take place. I am, therefore, of the opinion that the fact of the displacement of the warm and moist current from the Gulf by the colder air from the west and northwest is sufficient to account for the fluctuations of the barometer, in a great many instances, in places to the west of the Alleghany chain of mountains.

Professor Espy informs me that he has traced a central line of minimum pressure, which precedes the eastern storms on the Atlantic coast first in the western States. This line is of great length from north to south; and from an examination of his charts of the weather, in his Report on Meteorology, I was at once struck with the fact that its direction corresponds with the trough of the Mississippi valley, and with the course of the moist winds from the Gulf of Mexico. In Europe, I have often been enabled to trace the connexion between the fluctuations of the barometer and changes in the temperature and moisture of the air; but I have never found the connexions so regular and intimate as in the Mississippi valley, which is more removed from influences which tend to disturb this action.

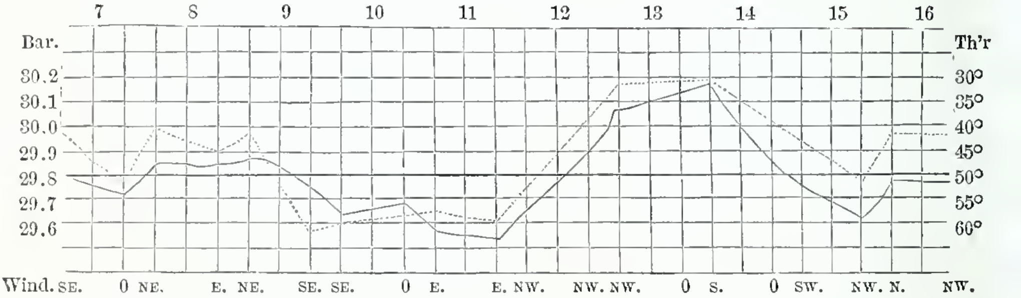
In my last lecture I showed that the temperature of the air at sunrise is, as a general rule, a close approximation to the dew point. A high dew point, or, in other words, a large amount of vapor, has the effect, as we have before said, of maintaining the warmth of the air during the night.

The observations collected by the Smithsonian Institution give the temperature at 7, A. M., and 9, P. M. As a rise or fall in the temperature at these hours may be considered as indicating an increase or decrease in the amount of moisture in the air, and as the fluctuations of the barometer are also given for the same hours, I have, therefore, in the diagrams, [figures 1, 2, 3, 4,] shown the connexion which exists between the heat and moisture of the air and the changes in the pressure.

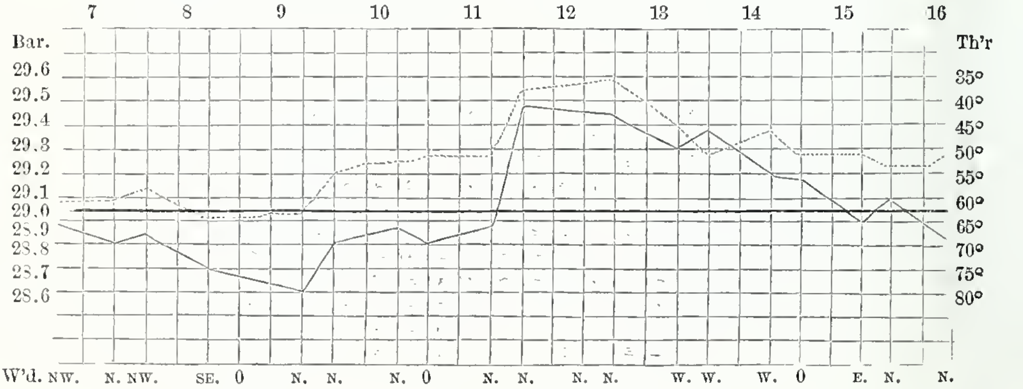
I have compared the temperature taken at 7, A. M., and 9, P. M., leaving out the day temperature altogether. The temperature at these hours, as I have stated, is a close approximation to the dew point. And this fact, which, as a general rule, holds true, especially in autumn, is the only means I possess to ascertain the hygrometrical state of the air during the storms of this country. The amount of vapor is an essential element in the investigation of atmospheric disturbances, and hence even an approximate estimate of the quantity is important.

The following curves of temperature and pressure of the atmosphere for 7, A. M., and 9, P. M., from the 7th to the 16th of November inclusive, are intended to illustrate the connexion between the moisture, temperature, and pressure, during a storm:

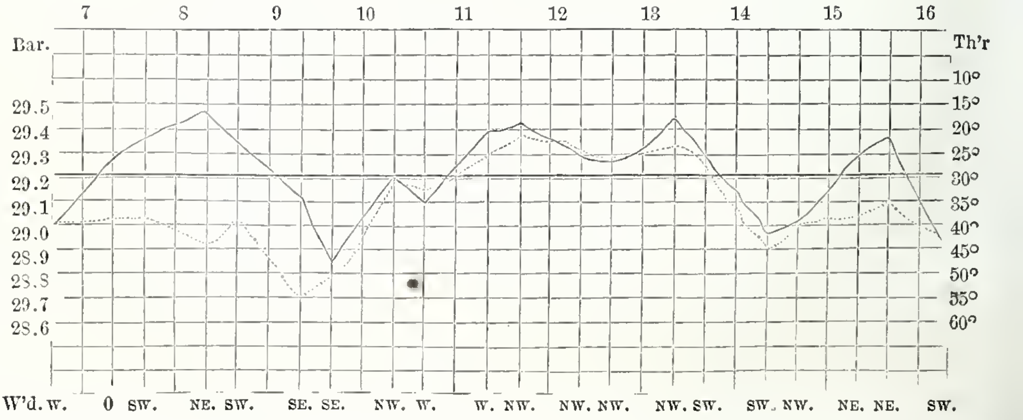
No. 1—*Curve of temperature and pressure for Tuscaloosa, Alabama. Latitude* 33° 12′ *N.*; *Longitude* 87° 12′ *W.*



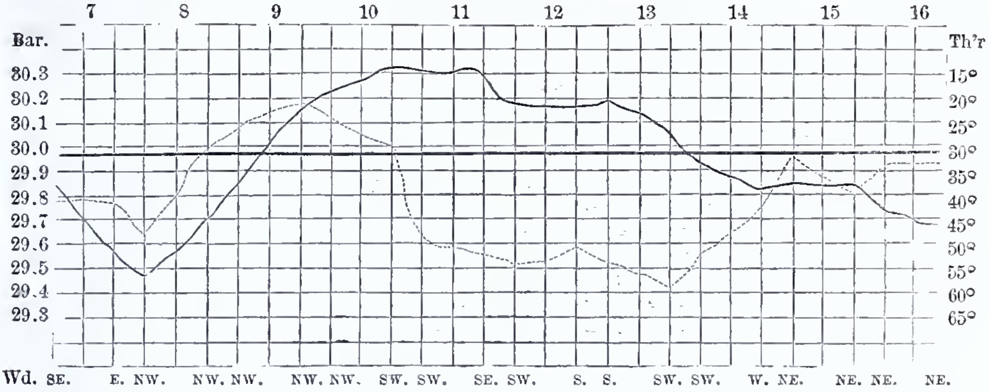
No. 2—*Curve of temperature and pressure for New Weid, Texas. Latitude* 29° 42′ *N.*; *Longitude* 97° 0′ *W.*



No. 3—*Curve of temperature and pressure for Milwaukie, Wisconsin. Latitude* 43° 3′ *N.*; *Longitude* 87° 57′ *W.*



No. 4—*Curve of temperature and pressure for Steuben, Washington county, Maine. Latitude 44° 44′ N.; Longitude 67° 50′ W.*



The continuous line represents the changes of the barometer, and the dotted line those of the thermometer. The figures on the left-hand margin of the wood-cut indicate heights of the barometer in intervals of one-tenth of an inch, and those on the right hand side, of the thermometer in intervals of five degrees of Fahrenheit's scale.

The figures along the upper margin indicate the days of the month during which the storm continued, and the letters along the lower the direction of the wind during the same time.

In order to exhibit more strikingly the relation of the temperature, moisture, and pressure, the dotted line is inverted so as to represent the highest point of the thermometer by the lowest point of the curve. With this arrangement the two curves in the first three figures are nearly parallel, showing that in the middle regions of the United States the abnormal depressions of the barometer are attended with a rise in the thermometer and consequently an increase of moisture, while in the eastern States, as illustrated by figure 4, the result is almost entirely opposite—the increase of temperature is accompanied with a rise in the barometer.

If we suppose that a south wind, of 10,000 feet in height, with a temperature of 70°, occupies the Mississippi valley, and the upper current from the west flows across its surface, in ordinary circumstances this stratum of air would weigh a little more than nine inches of mercury. Now, if we further suppose a cold northwest wind, having its dew point or morning temperature down to 30°, to displace the warmer current, by crowding it to the east and occupying its place, as ten thousand feet of air at this low temperature weighs 1-12th more, or $\frac{3}{4}$ inch of mercury, this denser and colder column will cause a rise in the barometer to that extent. Now, if a decrease of temperature of 40° causes a rise of $\frac{3}{4}$ inch of mercury, a decrease of 5° would cause a rise of nearly 1-10th inch. This effect would be produced without taking into account the changes which might take place during storms in the upper strata of the atmosphere.

I have compared the fluctuations of the barometer at 7, A. M., and 9, P. M., with the changes in the temperature at these hours from the 7th to 16th November last, in the States of Maine, Vermont, New York, Michigan, Wisconsin, North Carolina, Kentucky, Missouri, East Florida, Alabama, Texas, and also at Washington. By making 5° of temperature correspond with 1-10th inch of mercury in the barometer, I find some very interesting results are brought out. In all the States south and west of the Alleghany range, the parallelism between the changes in the barometer and the changes in temperature are much greater than I anticipated. See figures Nos. 1, 2 and 3.

Some remarkable exceptions, however, occur, in which a rise of temperature is accompanied with a rise of the barometer. These exceptions are found to the east of the Alleghanies and the mountains of New England, where the curves of temperature and pressure of the air entirely lose the regularity which they possess in the southern and western States. The changes of the barometer before storms in the northeastern States appear to be very peculiar, at least I am acquainted with nothing like them in Europe. When the mercury rises a little above 30 inches in Great Britain, the index of the barometer points to "set fair," and an eastern storm rarely comes on before the mercury begins to sink. When the mercury is above 30 inches in Maine, during winter or autumn, a storm is often at hand, and the barometer does not fall before the weather gets colder and drier. An examination of the weather, from the 7th to 16th November last, (see figure 4,) apparently shows that the indications of the barometer, as a weather prophet, must be interpreted by a contrary rule to that which is observed in the western States and in England. The probable cause of this will be afterwards adverted to. I shall now proceed to give you an account of a general storm, which will serve to illustrate the principles I have stated:

The weather on the 12th November, 1854, presented a curious picture of extremes over the United States. The northwest wind was advancing like an extended wall, from Iowa to Texas, and clearing the whole country of its moisture. By looking at the following table of temperature for that day, we shall see the progress which it had made at the time mentioned:

Iowa, Poultney	11°	7, A. M.
Wisconsin, Madison	19°	"
Missouri, St. Louis	26°	"
Mississippi, Oxford	34°	9, P. M.
Texas, New Wied	36°	"

On the morning of the 12th the first killing frost was felt in Louisiana, and over Michigan, the northern parts of Illinois, Indiana, and Ohio, the ground was covered for the first time with snow. In these States the northwest wind was flowing beneath the colder edges of the southwest stream from the Gulf, forcing it to ascend and precipitate part of its moisture in the form of snow. As the under current rose it was caught by the upper current, and, as in the case of thunder storms, it was swept off towards the east. This at least seemed to be the process at Indianapolis, where, on the 12th, four inches of dry snow fell, while the lower wind from the north and northwest was overlaid by a current bearing clouds from the southwest. On the morning of the 13th, at the same place, the wind set in from the west.

On looking at the meteorological chart for the morning of the 12th, we perceive at a glance that the temperature gradually rises from Iowa to Maine, from Missouri to Savannah, and from Texas to Florida. The eastern seaboard States now experienced the southwest stream of moist and hot air—hotter and moister than it was in the west, because while this moveable current is gradually borne to the east its temperature is higher from having been blowing longer from a warmer quarter—on the same principle that an ordinary south wind in summer is warmer the second day it blows than on the first. The temperatures on the east coast are in very striking contrast to what they are on the west of the Mississippi.

Florida,	wind	SW.,	temperature	70°, rainy.
Savannah,	"	SE.,	"	64°, rainy.
North Carolina, Thornbury,	"	E.,	"	60°, rainy.
Washington,	"	W.,	"	48°, rainy.
New York,	"	WNE.,	"	53°, rainy.
Maine, Steuben,	"	SW.	"	54°, rainy.

The weather remained moist and warm on the 13th in the Atlantic States, but the cold air was rapidly advancing from the northwest. By the morning of the 14th it had swept the whole of the southwest current into the Atlantic and brought cold and clear weather. In Florida the temperature of 70° on the morning of the 12th was changed to the freezing by the 14th; frosts also occurred on the same day in Georgia, South Carolina, North Carolina, Virginia, Pennsylvania, and New York. It is worthy of observation that at the very time the northwest wind was making its cold felt from Florida to New York, the south wind, or a modification of it, had already set in over Texas, and raised the temperature 15°, and its influence was afterwards also felt as far north as St. Louis, in Missouri. This was merely the first stage of preparation for another atmospheric disturbance which was to run a similar course.

Striking changes in the temperature of the weather are produced in autumn by the colder wind from the west descending and bearing the moister stream before it; when this hot stream is extended along the Atlantic coast it in all probability becomes the vehicle of the hurricanes which proceed from the West Indian islands. A severe hurricane, having its course along the Florida coast, desolated the rice grounds on the Charles and Savannah rivers on the 8th September last; but a thunder storm, extending over the greater portion of the northern States, began on the 6th and travelled from northwest to southeast, causing a great atmospheric disturbance and lowering of the temperature.

We have only space to say a few words on the barometer during the storm of the 12th. Though rain and snow fell over an immense area that day, and the wind blew with great force in the Atlantic States, still the barometer was above the mean in the morning from Maine, in the east, to Wisconsin, in the west. In this section it is probable that the northwest current, overlying the whole storm, did not sweep away the ascending moist currents with sufficient rapidity, and hence the accumulation of air causing the barometer to rise before storms on the east coast. The Alleghany range must, so far, favor this accumulation by retarding or hindering the freer action of the winds from the west. When the air has a high temperature in summer, the increased pressure before storms is, I believe, not so much observed. In this storm, also, I find no traces of accumulation of air in Florida, where the curves or pressure and moisture coincide very accurately, as much so as they do throughout the Mississippi valley. The following reductions exhibit the state of the barometer over three sections of the United States. The figures show the difference of the pressure above or below the mean for the month, in hundredths of an inch:

First Section.

Maine	at 7 A. M.	+ .23 inches.
Vermont	" "	+ .21 "
New York (State).	" "	+ .33 "
Michigan	" "	+ .16 "
Wisconsin	" "	+ .21 "

Second Section.

North Carolina	at 7 A. M.	0 mean.
Kentucky	" "	— .17 inches.
Missouri	" "	+ .12 "

Third Section.

East Florida	at 7 A. M.	— .18 inches.
Alabama	" "	— .17 "
Texas	" "	+ .41 "

During the weather from the 7th to the 16th of November, the fluctuations of the barometer in the southern and western States do not seem to have been greater than could be ascribed to the changes of temperature. The great fall of the barometer in tropical storms, and the tornadoes of the United States, seem to me to admit of no other explanation than that given by Professor Espy, viz: an inward ascending column of air becoming much lighter from the extrication of latent caloric.

In regard to the winds, during the progress of this storm, only two systems are well developed. The northwest winds, on the 10th, were observed both in the rear and front, while the southwest current occupied the middle. The east wind is so partially developed, that we must regard it merely as an eddy in the more general system which embraces it. We cannot expect to find much regularity in the course of any set of winds, because this can only take place with an invariable temperature. Inequality of local temperature is the principal cause of the irregularity of the arrows which represent the direction of the wind on the meteorological chart.

On the 12th, the weather was very wet and stormy along the Atlantic States, and much rain also fell in the Ohio valley. Snow fell over a considerable area immediately to the south of the lakes.

We shall now very briefly trace the peculiarities of the weather and storms of Europe. The east wind very seldom blows over a large area of the United States, unless during storms. In northern Europe the case is very different: dry and cold winds are very common in spring, and, at this season, not only is the surface wind from the east, but the current in the higher regions is also from the same quarter. It usually bears cirrous clouds, thus showing the great height to which it extends in the atmosphere. So long as the east wind blows as an undivided current in winter, the weather is intensely cold in England. Coming over ranges of mountains and a long stretch of land, it is something like the west wind of the United States—as long as it is continuous, the cold is unabated; when the same wind prevails in summer the whole country is parched with drought; but when the surface east wind is overlaid by a current from the southwest, then the east wind becomes excessively wet and disagreeable. An east wind in Scotland is very rarely stormy either in summer or autumn, unless it has an upper current from the southwest. This upper current from the ocean supplies the moisture which is precipitated by the lower wind. After long periods of dry summer weather in Scotland, the barometer begins to fall several days before the rain storm comes on. The first symptoms of change are, usually, cirrous clouds floating in the upper regions of the atmosphere, and indicating a greater saturation going on above. Cumulous clouds at length form, and drift from southwest to northeast, often directly against the lower wind. A thunder storm begins the rainy season; and so long as the upper current continues, the east wind is rainy or moist.

The fall of the barometer, it would appear, arises from a warm and moist stratum of air taking the place of a colder one above; on the same principle as a moister and warmer one depresses the barometer in the Mississippi valley. For this reason the barometer is very much consulted as an indicator of changes in the weather in Great Britain.

The summer rain-storms often extend over a large area in Europe. I have traced the northeast wind blowing, as a broad current, from the Alps to the south of Scotland, while rain was falling over the greater part of this space.

The winter storms are also regulated by the same principles. When there is no upper current from the west, the east wind remains dry and cold; but when the southwest upper current begins to blow, it becomes wet and stormy, and almost all the great falls of snow in winter take place under these conditions. The barometer does not give as long a warning of an approaching storm in winter as it does in summer, but there is invariably a fall in the mercury before the storm comes on. To illustrate the character of our winter storms the following example is given:

During the month of December, 1853, the wind was, in general, east in England, not only at the surface of the ground but at great elevations in the atmosphere. The barometer was high and steady for that winter month. The rivers from the north to the south of the island were more ice-bound than they had been for 15 years.

On the 1st of January, 1854, the weather was very cold over Great Britain, as well as the northwest of Europe. There was no storm that day, and the temperature of the air did not differ much from Sandwich, in Orkney, to Brussels, in Belgium.

	Wind.	Temperature.	
		Max.	Min.
Sandwich Manse, Orkney	NW	28°	28°
Keleoliess, Fife	NW	34°	12°
Highfield, Nottingham	WNW	32°	14°
Liverpool, Lancashire	NNW	36°	= 27°

Holkham, Norfolk	W.	38°	= 20°
Helsten, Cornwall	NW.	41°	34°
St. Aubin, Jersey	NW.	35°	32°
Versailles, France	NW., calm	32°	24°
Brussels, Belgium	SW., calm	29°	24°
Heligoland, Denmark	N., stormy		

A disturbing element was, however, after a short time introduced; at Jersey the wind set in from the westsouthwest on the morning of the 2d, and a thaw commenced; the wind was high from this quarter at night, with heavy rain. A current also set in from the southwest, both at Versailles and Brussels, with snow falling more or less during the whole day. At Helsten, near Land's End in Cornwall, the wind was northeast, and 7-10th inch rain fell in the night; but it is quite evident that this rain, thrown down by the northeast wind, must have been derived from the upper current from the southwest, as the air still remained dry and frosty at Bath, on the west, and at Holkham, on the east. This supposition is rendered highly probable, from the fact that the upper stratum of clouds was from the southwest. It was some time before the storm was developed in the eastern counties.

The wind seems to have begun to blow very briskly from an easterly quarter over the south of England on the 3d, with much snow at night. An inch of rain fell that day in Jersey, with a squally wind from the east. The temperature remained low and the sky clear in Scotland and the north of England. The wind was from an easterly quarter that day at Paris, Brussels, and off the coast of Denmark. The southwest upper current, still prevailing, saturated the air all over England and the south of Scotland, and a violent storm of snow on the 4th was the result, which extended over a large portion of the west of Europe, the wind being easterly at almost all the different stations. It is curious to observe that no snow or rain fell at Helsten, near Land's End, on the 4th, the point to which all the wind on the east coast was blown; which shows that it must have been absorbed in some way before reaching the west coast. In Scotland the wind, on the 4th of January, was quite as violent as in the south of England; but very little snow fell on the eastern coast. A deep snow fell, with a strong northeast wind, at the temperature of 32°. The wind was excessively cold and dry in Aberdeen, being as low as + 9° max. — 6° min. The upper current had not influenced it sufficiently to raise the thermometer above these low temperatures. During this very low temperature in Aberdeenshire, the northeast wind was about 23° higher in Belfast. This difference of temperature is vastly greater than in the case of a sea breeze, and might alone account for the violent gale on the Irish coast.

The disturbance of the equilibrium of the atmosphere in this and our other winter storms seems to be occasioned, first, by a flowing away of part of the cold upper current, and a warmer and lighter air taking its place; and, second, by the denser air below flowing towards the warm and moist air over the ocean, which causes the saturated air to rise to a greater elevation, and condense its moisture. The condensed vapor, by the extrication of its caloric, favors ascending currents, which are gradually absorbed into the upper current and carried towards the earth. I have already mentioned that no snow or rain fell at Land's End while the day was nearly calm, and at the same time a violent hurricane, with much snow, was apparently blowing right towards this very locality. But this case exactly resembles the action of the sea breeze—the northeast wind being gradually absorbed into the upper current along the whole area over which it blows. The warming influence of the southwest upper current is well illustrated by the fact, stated to me by Mr. Moyle, that snow did not cover the ground for an hour last winter, though much fell with the northeast wind not far to the eastward of his place.

Though the storm had begun at Heligoland on the afternoon of the 5th, it did not reach Aberdeenshire on the 4th. The northeast winds were quite dry beyond this county; and the sky at Sandwich, in Orkney, was bright, and the air quite calm. Notwithstanding the prevalence of the easterly winds, we find that the temperature is advanced from west to east, especially along the western coast of Europe; and on the 6th, the upper current seems to have so completely worn away the lower current, that the wind was from the southwest on that day from Cornwall to Belgium. But in the north of England and over Scotland the lower current increased in depth, and for a time checked the warm upper current, or drove it back, and restored cold weather. All places under the influence of the southwest wind had their temperature raised, while those under the northeast had it depressed. This will be shown by the following table of temperature and direction of the wind:

Helsten,	S. W.	minimum	36°	Orkney	E.	minimum	23½°
Jersey,	S. S. W.	"	38°	Aberdeen	calm	"	10°
Paris,	S. W.	"	35°	Fifeshire	E.	"	30°
Brussels,	S. W.	"	34°	Liverpool	S. E.	"	30°

This may be taken as an example of our eastern storms. They are preceded by a fall of the barometer, but the manner in which they terminate has nothing of that regularity which distinguishes your storms. Very often the southwest wind blows as a deep current, and produces moist and warm weather in the depth of winter. The lower eastern wind, which is often very stormy, must be regarded as a mere surface stream, which is usually absorbed by the deeper upper current.

Now, I think it is very probable that an action similar to that of our northeastern storms is sometimes developed over the United States and in Canada. While I was sailing down the St. Lawrence, in the beginning of last October, a strong head wind prevailed from the northeast, at the same time that the clouds at no great height were drifting from the southwest. At Quebec, I also observed the same phenomenon; and, according to Professor Mitchell, of North Carolina, northeast storms are sometimes developed over large portions of the United States when the clouds are from the opposite quarter. I have had no opportunities since I have been in this country to examine the northeast rain storms, which appear to be more frequent in the New England States than to the south. But I suspect we must always bear in mind that an upper current flows from the west quarter even when the lower northeast wind and middle southwest current are prevailing.

There is another class of storms of very common occurrence in Great

Britain, during the continuance of which there are very rarely any east winds. There is also this peculiarity about them, that they seldom give warning of their approach by any fall in the barometer; indeed, it often shows a pressure above the mean just before they commence. The wind springs up from the southwest, and blows as a broad stream over the whole island, and in almost all these storms an upper current prevails from the northwest, which descends before the termination of the disturbance, and at once brings cold and dry weather. This particular form of atmospheric disturbance occurs at all seasons of the year, sometimes as a very gentle breeze, and often as storms of the most violent character. The changes of the wind are from southwest to northwest, crossing due west at once, and at this time blowing with their greatest violence. But our limits forbid us to enter further into this subject.

In the course of these lectures it has been my wish to state as clearly and distinctly as possible the general principles on which nearly all meteorologists are agreed, and to avoid, as far as might be, the discussions of points in reference to which there is less harmony of opinion. I have been anxious to place before you what I consider to be the distinctive features of the storms of North America and of Europe. I am quite aware that the topic would have furnished materials for a much greater number of lectures, but a mere outline was all that could be properly attempted in the time allotted. I have presented the phenomena in the connexion in which they now represent themselves to my mind. I may, however, have reason to modify my present views of American storms when I have found leisure to arrange and discuss more thoroughly the ample materials I have collected in my tour. But, whatever may be the change in this respect, I shall always retain a lively and constant impression of the kindness, the hospitality, and the liberality which I have everywhere met with in my travels through this favored land.

APPENDIX TO MR. RUSSELL'S LECTURES, BY THE SECRETARY OF THE SMITHSONIAN INSTITUTION.

As an appendix to Mr. Russell's lectures, we give the following tables, showing the mean diurnal variations of the temperature, moisture, pressure, &c., of the air. The principal series are from observations made at Greenwich, near London, under the direction of Mr. Glaishier. The tables for Bombay are from the observations of Dr. Buist, those for Philadelphia are from the valuable series made under the direction of Professor Bache at Girard College.

By a comparison of the quantities given, it will be seen that all the changes are connected with and depend upon the position of the sun in the heavens, or, in other words, upon the amount of solar heat received at the different hours of the day. The numbers given in the series for Greenwich are deduced from the observations continued for several years, comprising more than 20,000 individual records, and, therefore, abnormal variations are eliminated, and the special changes due to constant causes are exhibited in their true values.

Table I gives the mean diurnal variation of the temperature of the air in the shade at intervals of two hours, from 2 o'clock in the morning until the end of the 24 hours. It will be seen by this table that on the average the coldest period of the day is a little before sunrise, and that the temperature of the air remains nearly stationary from about 4 o'clock until near 6 o'clock in the morning, that it then gradually rises until 2 p. m., when it reaches its maximum, and then declines. The first rays of the sun are probably expended in vaporizing the dew and moisture at the surface of the earth, and as this process renders a large portion of heat latent the air does not increase very rapidly in temperature.

TABLE I.

MEAN DIURNAL VARIATION OF TEMPERATURE AT GREENWICH.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
45° 4'	44° 8'	44° 8'	46° 9'	50° 4'	53° 6'	55° 1'	54° 5'	52° 3'	49° 5'	47° 5'	46° 3'

— Minimum.

+ Maximum.

TABLE II.

MEAN DIURNAL VARIATION OF THE WEIGHT OF WATER IN A CUBIC FOOT OF AIR AT GREENWICH.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
GR. 3.52	GR. 3.49	GR. 3.51	GR. 3.64	GR. 3.78	GR. 3.88	GR. 3.92	GR. 3.89	GR. 3.79	GR. 3.71	GR. 3.63	GR. 3.58

— Minimum.

+ Maximum.

Table No. II gives the mean diurnal variation of the absolute weight in grains of moisture in a cubic foot of the air, as determined by a series of calculations from the record of the observations of the wet and dry bulb thermometer.

It will be seen by a comparison of table No. II with table No. I that as the temperature increases, the amount of water which exists in the air as vapor also increases. The two elements heat and moisture mutually influence each other as to the quantity present in the atmosphere at a given time. With an increase of elevation of the sun above the horizon its rays pass to the earth through the atmosphere less obliquely and impinge more perpendicularly on the surface. This produces an increased amount of vapor, with an increased elastic force, which enables the air in turn to absorb and retain a larger quantity of heat.

The maximum quantity of moisture is at 2 p. m. The increase in weight is from about 3½ grains to near 4 grains.

This table, however, does not give the amount of vapor which the air could hold if sufficient moisture were present to entirely saturate it. Indeed the air is very seldom fully saturated, and in order to begin to precipitate the vapor it contains into water, it is generally necessary to lower the temperature quite a number of degrees. The point of temperature at which the moisture begins to settle—for example, on the surface of a bright tin cup partly filled with water which is slowly cooled down by gradually adding ice water—is called the *dew point.* The greater number of degrees the water is obliged to be lowered before dew begins to be deposited, or the greater the difference between the temperature of the air and the dew point the greater is the dryness of the air, or the greater is the tendency of vapor to exhale from the skin and from all bodies containing moisture.

Table No. III gives the mean diurnal variation in the dew point.

TABLE III.

MEAN DIURNAL VARIATION OF THE DEW POINT AT GREENWICH.

2 A. M.	4 A. M.	6 .M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
43° 1′	42° 9′	42° 9′	44° 0′	45° 2′	46° 2′	46° 5′	46° 3′	45° 6′	44° 7′	44° 1′	43° 6′

— Minimum.

+ Maximum.

If we subtract the numbers in this table from those in Table No. 1, we shall have approximately the relative dryness, or evaporating power of the air; this is given in No. IV.

TABLE IV.

MEAN DIURNAL VARIATION OF DRYNESS, (APPROXIMATELY,) AT GREENWICH.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT
2° 3′	1° 9′	1° 9′	2° 9′	5 2′	7° 4′	8° 6′	8° 2′	6° 7′	4° 8′	3° 4	2° 7′

— Minimum.

+ Maximum.

From this it appears that the minimum dryness or greatest dampness of the air also occurs at four o'clock in the morning, and the maximum dryness at two o'clock in the afternoon.

The degree of humidity, however, of the air, may be more definitely expressed by the result of a more laborious process, namely, by dividing the weight of water in the air at a given time by the whole quantity the air could hold if it were saturated. By making the necessary calculation, and considering the point of saturation as unity, we shall have the following table:

TABLE V.

MEAN DIURNAL VARIATION OF THE HUMIDITY OF THE AIR AT GREENWICH

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
0.926	0.934	0.938	0.906	0.843	0.783	0.753	0.761	0.800	0.851	0.891	0.914

+ Maximum. — Minimum.

When the quantity of water is in the least degree greater than the atmosphere can contain at a given temperature, condensation takes place, which may be either in the form of fogs or dew in the lower strata or clouds, and rain in the upper. The formation of clouds will therefore depend on the amount of moisture in the atmosphere. This is shown by

TABLE VI.

MEAN DIURNAL VARIATION OF THE CLOUDINESS OF THE ATMOSPHERE AT GREENWICH.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
.65	.67	.69	.70	.71	.71	.71	.69	.66	.62	.60	.61

+ Maximum. — Minimum.

The actual weight of a given portion of the air is also affected by the variation of temperature. This is shown in the following table, in which the minimum of weight occurs at the hour of maximum temperature.

TABLE VII.

MEAN DIURNAL VARIATION OF THE WEIGHT OF A CUBIC FOOT OF AIR AT GREENWICH.

2 A. M.	4 A. M	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
Gr. 541.7	Gr. 542.2	Gr. 542.2	Gr. 540.1	Gr. 536.3	Gr. 532.9	Gr. 531.0	Gr. 531.5	Gr. 533.9	Gr. 537.2	Gr. 539.4	Gr. 540.6

+ Maximum. — Minimum.

The next table, which gives the variation of the barometer, shows that the indications of this instrument are not precisely the same as those obtained by actually weighing a portion of air. The table exhibits two maxima and two minima in the course of the twenty-four hours.

TABLE VIII.

MEAN DIURNAL VARIATION OF ATMOSPHERIC PRESSURE AT GREENWICH.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
29.773	.765	.766	.776	.786	.785	.774	.767	.768	.777	.784	.784
	— Minimum.			+ Maximum.			— Minimum.				+ Maximum.

At first sight, it might appear that the weight and pressure, or in other words the density and pressure, ought to vary together, but a little reflection will make it plain that an increase of pressure on a portion of the surface of the earth may be counteracted by a variation of temperature. The height of the barometer indicates the weight of a column of air, extending to the top of the atmosphere; now, this column may be unduly heated at one point, as we ascend, and unduly cooled at another, and while the absolute weight of a portion of the air at any point of the column may vary, the pressure of the whole column may remain the same, or the converse. It is probable, however, that the variation of the weight which is found at the surface does not extend to a great elevation, and that when it is not indicated by the barometer it is because the change is too small to be noted by that instrument.

The fact that the barometer exhibits two maxima and two minima in the course of the twenty-four hours has given rise to much speculation as to its cause. The most common explanation is, that it is due to the joint action of the variation of the temperature and moisture. In the morning, the moisture rising into the atmosphere increases the weight of the air more than the heat diminishes it by expansion, while at about ten o'clock, a. m., the effect of heat overbalances that of vapor, and again as the sun begins to decline, the weight of the latter predominates. Mr. Espy attributes the daily oscillations of the barometer to the upward and downward motion of the particles of air and moisture as they are separated or approximated by the change of temperature. The particles weigh more while the rate of separation is increasing, and less while it is diminishing. This is a true cause, but we are not certain that it is a sufficient one. Whatever may be the cause of the daily oscillations of the barometer, we know the effect is nearly the same in parts of the earth most widely separated.

The diurnal variation of the pressure of the wind is also intimately connected with the variation of the temperature and weight of the air; this is shown by the following table, which gives the sums of the pressure upon a square foot in pounds avoirdupois at each hour of the 24. The numbers are those given by Osler's self-registering anemometer.

TABLE IX.

MEAN DIURNAL VARIATION OF THE PRESSURE OF THE WIND AT GREENWICH.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
603¼	584¼	546	558½	575	585¾	650¾	781	906¾	1.008¾	1.204½	1.360

—
Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
1.405¼	1.415¼	1.323¼	1.187	1.032½	874	721	649¼	649¾	634	650½	642¼

+
Maximum.

For the purpose of comparison, and to illustrate the fact that the diurnal variations of the meteorological elements follow the same general law in the parts of the earth the most widely separated, the following tables are given from observations made at Bombay:

TABLE X.

MEAN DIURNAL VARIATION OF TEMPERATURE AT BOMBAY, 1843.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
79° 4'	78° 9'	78° 4'	79° 6'	81° 8'	83° 2'	84° 1'	83° 9'	82° 3'	81° 2'	80° 3'	79° 8'

— +
Minimum. Maximum.

The minimum temperature in this table occurs at 6 a. m., and the maximum at 2 p. m.

TABLE XI.

MEAN DIURNAL VARIATION OF TENSION OF VAPOR AT BOMBAY, 1843.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
0.766	0.761	0.750	0.766	0.771	0.778	0.795	0.800	0.802	0.801	0.780	0.775

— +
Minimum. Maximum.

According to this table the tension or elastic force of vapor at Bombay arrives at its minimum at 6 a. m., and its maximum not until 6 p. m. This difference in the time of the maximum and minumum at Bombay and Greenwich probably arises from the tropical position of the former.

TABLE XII.

MEAN DIURNAL VARIATION OF THE BAROMETER AT BOMBAY, 1843.

2 A. M.	4 A. M.	6 A. M.	8 A. M.	10 A. M.	NOON.	2 P. M.	4 P. M.	6 P. M.	8 P. M.	10 P. M.	12 NIGHT.
In. 29.786	In. 29.778	In. 29.805	In. 29.840	In. 29.852	In. 29.817	In. 29.776	In. 29.755	In. 29.774	In. 29.806	In. 29.825	In. 29.809
	— Minimum.			+ Maximum.			— Minimum.			+ Maximum.	

This table exhibits, as in the case of that for Greenwich, two maxima and two minima.

The following tables exhibit the mean diurnal variations in the meteorological elements at Girard College, Philadelphia. They present the result of the observations for each hour of the 24.

TABLE XIII.

MEAN DIURNAL VARIATION OF THE TEMPERATURE OF THE AIR AT PHILADELPHIA.

Computed from the observations made in 1842, *and from the* 1st *July*, 1843, *to the* 1st *July*, 1845.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
48.2	47.8	47.3	46.8	46.6	47.0	48.1	50.1	52.1	54.1	55.7	56.8
				— Minimum.							

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
57.9	58.6	58.9	58.7	57.7	56.0	54.1	52.5	51.0	50.2	49.4	48.7
		+ Maximum.									

By comparing table XIII with table I, it appears that the diurnal variation of temperature, at Greenwich and Philadelphia, is nearly the same. The minimum occurs a little earlier at the latter, and the maximum a little later.

TABLE XIV.

MEAN DIURNAL VARIATION OF THE DEW-POINT AT PHILADELPHIA.

Computed from the observations made from the 1st *July*, 1843, *to* 1st *July*, 1845.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
42.0	41.7	41.4	41.1	41.1	41.4	42.0	42.9	43.7	44.1	44.3	44.5

—
Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
44.7	44.6	44.5	44.1	43.7	43.7	43.6	43.3	43.1	42.9	42.7	42.3

+
Maximum.

The variations of the figures, in table XIV and table III, also follow the same general law.

TABLE XV.

MEAN DIURNAL VARIATION OF DRYNESS, (APPROXIMATELY,) AT PHILADELPHIA.

Computed from the observations made from July 1, 1843, *to July* 1, 1845.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
6.1	6.2	5.7	5.6	5.3	5.4	6.0	6.9	8.2	10.0	11.3	12.3

—
Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
13.3	14.1	14.5	14.8	14.2	12.6	10.7	9.4	8.3	7.4	6.8	6.4

+
Maximum.

From table XV, it does not appear that Mr. Russell's rule, for ascertaining the dew point from the minimum temperature, holds true in Philadelphia. Table No. IV, gives a much nearer approximation, and, in moist seasons, the same will probably be the case in this country, particularly at the south. By comparing the quantities given in table No. XV, with those in table No. IV, it will be seen that the relative dryness of Philadelphia is much greater than that of London or Greenwich.

TABLE XVI.

MEAN DIURNAL VARIATION OF THE CALCULATED FORCE OF VAPOR AT PHILADELPHIA.

Computed from the observations made in 1842, *and from July* 1, 1843, *to July* 1, 1845.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
.344	.341	.334	.335	.333	.336	.343	.351	.359	.363	.365	.369

—
Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
.371	.375	.375	.373	.376	.376	.372	.364	.358	.353	.350	.348

+
Maximum.

TABLE XVII.

MEAN DIURNAL VARIATION OF ATMOSPHERIC PRESSURE, BAROMETER REDUCED, AT PHILADA.

Computed from the observations made in 1842, *and from July* 1, 1843, *to July* 1, 1845.

1 A. M.	2. A M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
29.938	29.936	29.933	29.935	29.941	29.951	29.960	29.966	29.969	29.967	29.958	29.944

— Minimum. + Maximum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 A. M.	11 A. M.	12 NIGHT.
29.927	29.916	29.910	29.909	29.911	29.918	29.927	29.935	29.943	29.946	29.949	29.941

— Minimum. + Maximum.

Table XVII shows two maxima and two minima in the height of the barometer, which correspond very nearly in time with those of table VIII for Greenwich.

TABLE XVIII.

MEAN DIURNAL VARIATION OF THE FORCE OF WIND, IN POUNDS, AT PHILADELPHIA.

Computed from the observations made in 1843 *and* 1844.

1 A. M.	2 A. M.	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
.50	.50	.52	.53	.51	.47	.47	.56	.64	.80	.88	.98

+ Maximum. — Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
1.02	1.03	1.03	.98	.82	.61	.59	.50	.51	.52	.50	.47

+ Maximum. — Minimum.

Table XVIII, compared with table IX, exhibits a greater mean pressure of the wind at Greenwich than at Philadelphia. The maximum intensity, during the whole 24 hours is, in both tables, at 2 P. M.

TABLE XIX.

MEAN DIURNAL VARIATION OF THE SKY COVERED BY CLOUDS, AT PHILADELPHIA.

Computed from the observations made from the 1st *July*, 1843, *to* 1st *July*, 1845.

1 A. M.	2 A. M	3 A. M.	4 A. M.	5 A. M.	6 A. M.	7 A. M.	8 A. M.	9 A. M.	10 A. M.	11 A. M.	NOON.
.60	.61	.61	.65	.70	.74	.79	.86	.83	.85	.86	.88

— Minimum.

1 P. M.	2 P. M.	3 P. M.	4 P. M.	5 P. M.	6 P. M.	7 P. M.	8 P. M.	9 P. M.	10 P. M.	11 P. M.	12 NIGHT.
.88	.89	.87	.88	.83	.80	.74	.69	65	.64	.65	.63

+ Maximum.

Tables XIX and VI exhibit nearly the same variation in the time of greatest and least cloudiness at Greenwich and Philadelphia.